

A White Shrimp Mark-Recapture Study¹

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ABSTRACT

Marked sub-adult white shrimp were released in Galveston Bay in August 1963. Recoveries indicated there was no emigration from the bay between August and mid-October. Using the Bertalanffy growth function estimates of L_{∞} equals 214 mm, $K = 0.09$ (sexes combined). Shrimp increased rapidly in size, 98 to 133 mm in 4 wk and to 146 mm in 6 wk during the warm summer months. Reliable estimates of natural and fishing mortality could not be obtained. Several techniques were used to obtain estimates but they varied to such a degree that results were questionable. Probable causes of these inaccurate estimates are nonrandom distribution of the marked population, fishing effort, or a combination of both.

One responsibility of the National Marine Fisheries Service is to determine the maximum exploitation of shrimp stocks in the Gulf of Mexico on a continuing basis. This requires a measurement of the average rate of growth and mortality for each stock concerned. One direct means for estimating these population parameters is by mark-recapture studies.

Mark-recapture experiments with biological stains as marks have been conducted with the three commercial species along the Gulf coast; the white, brown, and pink shrimps, *Penaeus setiferus*, *P. aztecus*, and *P. duorarum*, respectively. The experiments with pink shrimp yielded information concerning vital population parameters and provided an opportunity to assess the yield of a shrimp stock (Kutkuhn 1966; Berry 1967, 1969). Preliminary population dynamic information on brown and white shrimp stocks off Texas and Louisiana were obtained from marking studies in the spring and fall of 1962 (Klima 1964). Additional information concerning white shrimp population parameters was obtained from a marking experiment in Galveston Bay between August and October 1963. Results provided estimates of the growth parameters during the summer, a portion of the life history when exploitation is greatest.

FISHERY

White shrimp in the Gulf of Mexico are found on soft muddy bottoms on the Continental Shelf. Commercially, they are harvested in near-shore waters in depths to 36.6 m (20 fathoms) although they are occasionally found at depths to 82.3 m (45 fathoms) (Springer and Bullis 1952). The largest commercial concentrations occur between Apalachicola, Florida and central Texas with the highest densities found in and adjacent to Louisiana and eastern Texas estuaries (Lindner and Cook 1970).

Kutkuhn (1962) reviewed the distribution, habitat, and method of capture of white shrimp. He discussed population characteristics and their apparent relation to changes in environment and intensity of exploitation. Wide fluctuations were noted in the commercial yield from year to year between 1956-1959. These were attributed mainly to changes in the environment but excessive fishing after adverse climatic conditions may stifle a rapid population recovery. Examination of commercial catch statistics from the Mississippi River to central Texas for the period 1960-1963 revealed similar yearly fluctuations.

Yearly fluctuations in population density are characteristic of white shrimp. In waters adjacent to Galveston, Texas, maximum numbers of commercial size white shrimp occur from September to December. In recent years (1960-1963) the fall fishery has produced more than 90% of the total white shrimp catch.

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The first seasonal peak of young-of-the-year, which supports the offshore fishery, enter the Galveston Bay complex between May and June (Baxter and Renfro 1967). They attain catchable size by mid-August in the bay and provide the main supply for this fishery for several months, then move offshore with the advance of cooler water temperatures (Pullen and Trent 1969). About 400 boats commercially fish throughout the bay from August to January, with the maximum fishing effort expended at the beginning of the season in August. It decreases slowly to the end of October and by November and December only a few boats remain fishing. The offshore fishery usually begins in late September or October and continues through December.

Commercial catch statistics for the years 1960–1963 reveal the average annual catch of white shrimp from the bay is almost 6,803 metric tons, whereas average annual offshore catch for this period is 5,442 metric tons.

METHODS

Shrimp to be marked were caught in Galveston Bay with 4.6-m otter trawls towed from a skiff and the shrimp placed into live wells. The shrimp were then transported to the staining site and placed into large tanks of sea-water.

Shrimp of a uniform size were released because (1) one must know the size of individual shrimp to estimate growth rates, and (2) the stain-injection method of marking did not permit identity of individual shrimp. Shrimp 90 to 99 mm total length were marked with an aqueous solution of 0.5% fast green FCF by the methods described by Costello (1964).

After being marked, they were held 18 hr before release. All shrimp in poor condition were discarded. Stained shrimp were released in groups of 50 or less in Trinity and upper Galveston Bays with a total of 3,115 released between 13–16 August (Fig. 1).

Posters describing the program were distributed to commercial fish plants and bait stands around Galveston Bay and a reward of \$2.00 was offered for the return of each stained shrimp and pertinent recapture data.

Recovery data from Galveston Bay were

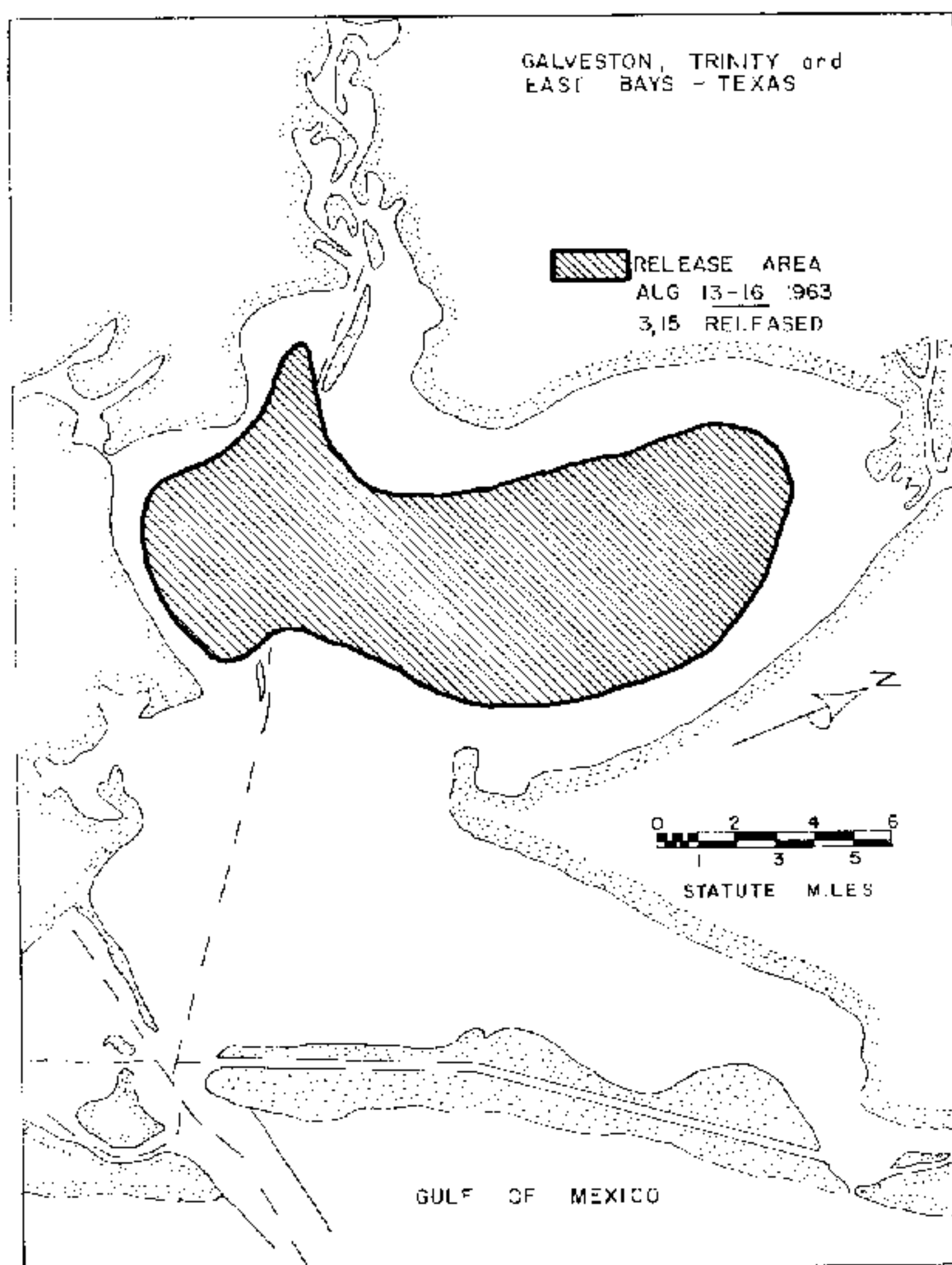


FIGURE 1.—Map of Galveston Bay showing the release site of marked white shrimp (13–16 August 1963).

suitable for measuring the average growth rate for sub-adult and adult white shrimp during the summer. Regulation of the shrimp fishery is impractical on the basis of sex; therefore, growth data of males and females were combined. The growth parameters obtained from sexes-combined data may be interpreted as lying intermediate between the true value of females and males since females grow larger than males. Hence, if the sex ratio of the recoveries is unchanged, it is possible to combine data from males and females and obtain an average growth estimate. A chi-square test on the number of male and female shrimp recovered in each 7-day time interval indicated no change in the sex composition of recoveries

$$(\chi^2 = 11.73 < \chi^2_{.95(7)} = 14.07).$$

Recovery data were grouped into successive 7-day units and average lengths were calculated for each time interval (Table 1). Ludwig von Bertalanffy's (1938) growth-in-length equation was used to describe growth.

TABLE 1.—Average length (in mm) of marked white shrimp recaptured during successive weeks of the Galveston Bay experiment (August–October 1963)^a

Time period (dates)	Female			Male			Sexes combined		
	Sample size (no.)	Average length (mm)	Standard deviation (mm)	Sample size (no.)	Average length (mm)	Standard deviation (mm)	Sample size (no.)	Average length (mm)	Standard deviation (mm)
21 Aug–27 Aug	56	103.5	5.3	44	101.8	5.0	100	102.7	5.5
28 Aug–3 Sep	32	111.4	7.2	35	113.0	5.9	67	112.3	6.7
4 Sep–10 Sep	17	120.6	5.3	29	121.8	5.5	46	121.4	5.5
11 Sep–17 Sep	7	128.3	3.0	15	129.9	8.1	22	129.4	6.7
18 Sep–24 Sep	9	137.3	5.2	18	136.4	6.7	27	136.7	6.0
25 Sep–1 Oct	5	142.4	6.9	4	146.3	3.3	9	144.1	5.9
2 Oct–8 Oct	7	153.1	9.2	4	145.8	7.9	11	150.5	9.4
9 Oct–15 Oct	2	152.5	0.3	3	157.7	2.1	5	155.6	3.0

^a Includes only shrimp which could be measured.

I obtained estimates of the parameters K and L_{∞} by a straight-line to a Walford plot of the average lengths and used Ricker's (1958) method to determine the parameter t_0 .

RESULTS AND DISCUSSION

Growth

Growth curves have been computed for several species of penaeid shrimp (Lindner and Anderson 1956; Iversen and Jones 1961; Neiva and Wise 1964; Klima 1964; Kutkuhn 1966). These authors described growth over various portions of a year by the growth-in-length equation derived by von Bertalanffy (1938) as:

$$L_t = L_{\infty}(1 - e^{-K(t-t_0)})$$

where L_{∞} is the average maximum size, K is the coefficient of catabolism, t_0 is the age at which length is zero and L_t is the length at time t .

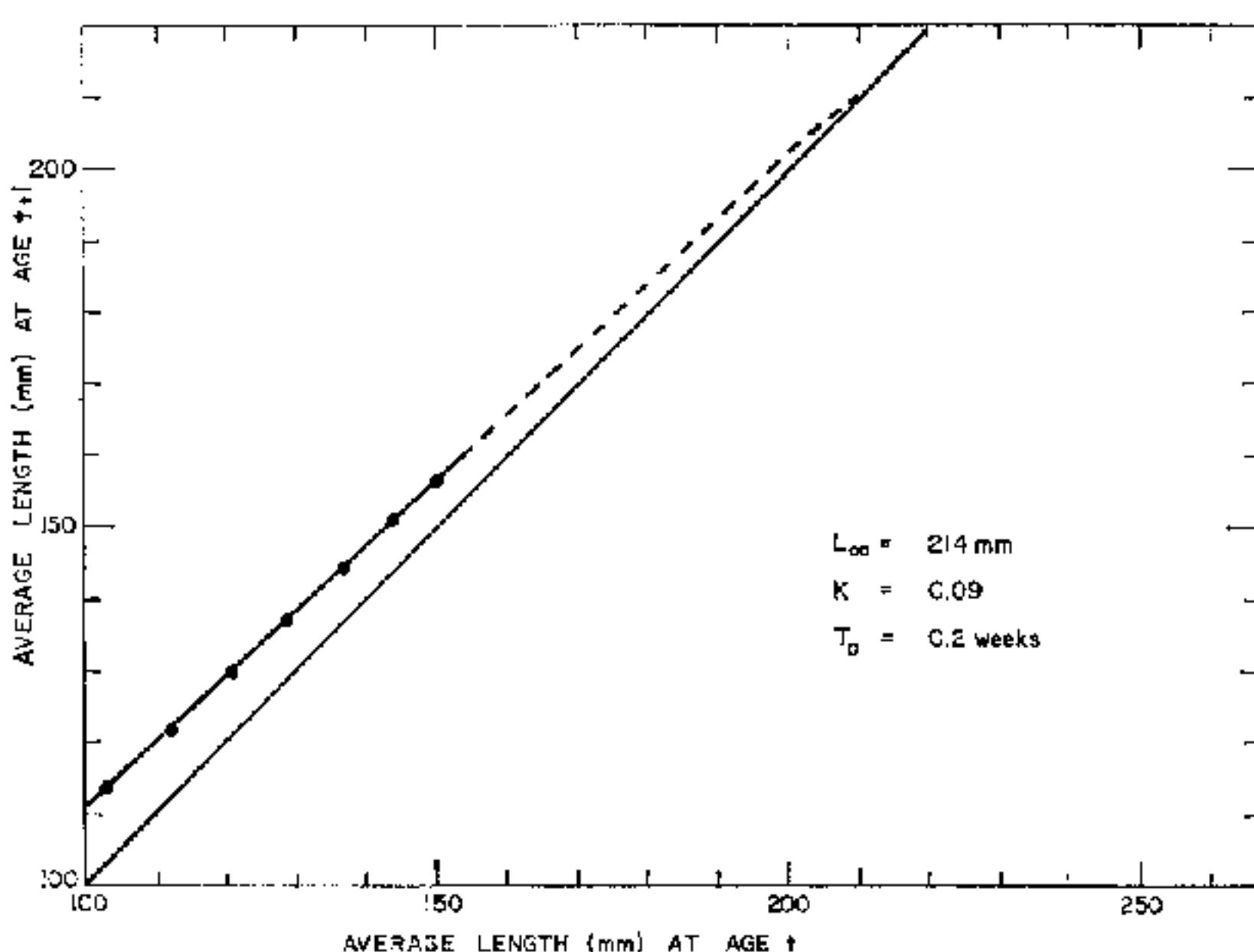


FIGURE 2.—Walford graph of average length in millimeters at age $t+1$ against length at age t ($t=7$ days).

Growth parameters of Galveston Bay white shrimp from mid-August through September were $K = 0.09$, $L_{\infty} = 214$ mm, and $t_0 = 0.2$ wk (Fig. 2). Although these values are based on a short period in the shrimp's life (Table 1), they provide information describing growth when exploitation is at a peak.

Based on the above parameters, white shrimp increase in size from 103-count heads-off (98 mm) to 40-count (133 mm) in 4 wk and to 30-count (146 mm) in 6 wk. This growth rate during the warm summer months is considerably faster than that estimated by Klima (1964) for white shrimp during late summer and early fall where $L_{\infty} = 224$ mm and $K = 0.06$ (Table 2).

Variation of growth parameters with changes in water temperature has been documented for cod, razor clam, and Pacific cockle by Taylor (1958, 1959, and 1960). The growth rate of postlarval brown shrimp and white shrimp increases with temperature (Zein-Eldin and Griffith 1965, 1969). Esti-

TABLE 2.—Comparison of calculated lengths of white shrimp (sexes combined) from Galveston Bay experiment, August 1963, with those (sexes combined) for mark-recapture experiments off Louisiana during late summer and early fall by Klima (1964)

Time in weeks	Total length in mm from Klima (1964)		Total length in mm from Galveston Bay mark-recapture experiment	
	Increase in length		August 1963	Increase in length
0	120		117 ^a	
4	141	21	146	29
8	159	18	167	21

^a Lengths were derived from the growth formula of von Bertalanffy.

TABLE 3.—*Recovery of marked shrimp and related fishing effort (in boat days) grouped into time intervals along with calculated mortality coefficients for three different time groups, F, X, and Z are adjusted to a 10-day time interval*

Time period 1, 2, and 3	Length of period	Recov- eries	Fishing effort	Calculated instantaneous mortality rates								
				Time period 1			Time period 2			Time period 3		
				F ₁	X ₁	Z ₁	F ₂	X ₂	Z ₂	F ₃	X ₃	Z ₃
Dates	Days	Number	Boat days									
16 Aug-24 Aug ^a	9	178	1,574							0.279	0.058	0.337
16 Aug-25 Aug ^b	10	190	1,693	0.227	0.173	0.400	0.261	0.136	0.397			
25 Aug-2 Sep	9	91	1,307							0.232	0.058	0.290
26 Aug-3 Sep	9	93	1,305	0.175	0.156	0.331	0.201	0.123	0.324			
3 Sep-11 Sep	9	63	1,088							0.193	0.058	0.251
4 Sep-11 Sep	8	49	971	0.130	0.138	0.268	0.150	0.109	0.259			
12 Sep-20 Sep	9	28	675							0.120	0.058	0.178
12 Sep-21 Sep	10	33	792	0.106	0.173	0.279	0.122	0.136	0.258			
21 Sep-29 Sep	9	27	873							0.155	0.058	0.213
22 Sep-29 Sep	8	22	756	0.101	0.138	0.239	0.116	0.109	0.225			
30 Sep-8 Oct	9	13	486							0.086	0.058	0.144
30 Sep-8 Oct	9	13	486	0.065	0.156	0.221						
Totals	108	800	12,006	0.804	0.934	1.738	0.850	0.613	1.463	1.065	0.348	1.413
Average weekly instantaneous mortality rates				0.104	0.121	0.225	0.131	0.095	0.226	0.123	0.041	0.164
Average weekly mortality expressed in percent				9.9	11.4	20.1	12.3	9.1	20.2	11.6	4.0	15.1
				0.000134			0.000154			0.00016		

^a Time period 3.^b Time period 1 and 2.

mates of the parameters K and L_{∞} differ when calculated with seasonal recovery data from different portions of the year exhibiting different thermal environments. The disparity between the differences in estimated growth rates of white shrimp in Galveston Bay and Louisiana can be explained by the respective differences in the environment. For example, the inshore water temperature off Louisiana during the marking study of Klima (1964) ranged from 15 to 28 C, whereas water temperatures in Galveston Bay during the present investigation ranged from 24 to 30 C.

Reliability of growth parameters from mark-recapture studies raises the question as to whether the mark used affects growth. The effects of fast green FCF on the physiology and growth of brown shrimp has been investigated (Zein-Eldin and Klima 1965). They indicated that such stains did not grossly effect the metabolic rate of their shrimp. These findings increase the confidence placed on the growth parameter estimates obtained in this study.

Mortality

Estimates of mortality coefficients for brown and pink shrimp have been calculated

by Klima (1964) and Kutkuhn (1966). Methods used to estimate these coefficients varied slightly because the rate of exploitation of brown shrimp was constant, whereas it was not with pink shrimp. Klima (1964) used Beverton's and Holt's (1957) formulas 14.15 and 14.16 to estimate fishing and natural mortality coefficients. These remained constant throughout the study period. Kutkuhn (1966) used Beverton's and Holt's (1957) formula 14.19 because of abrupt changes in fishing effort.

Fishing effort on Galveston Bay white shrimp populations fluctuated throughout the study period (Table 3) necessitating the use of Beverton's and Holt's (1957) equation 14.19. This equation relates the ratio of recapture in pairs of successive time intervals to fishing effort. Solutions were calculated from the regression line of best fit of the recapture ratios for pairs of successive time intervals plotted against fishing effort. The slope provides an estimate of c and the Y intercept an estimate of X , the other loss coefficient including natural mortality.

With the recapture data listed in Table 3, solutions for X and c were calculated. I first computed mortality rates by grouping

TABLE 4.—*Distribution of marked recoveries by 7-day intervals with corresponding fishing effort^a (in boat days)*

Time period (Dates)	Upper Galveston Bay		Lower Galveston Bay		Offshore Gulf of Mexico	
	Number recovered	Fishing effort (Boat days)	Number recovered	Fishing effort (Boat days)	Number recovered	Fishing effort (Boat days)
15–21 Aug	98	813	13	474	0	415
22–28 Aug	82	629	9	451	0	415
29 Aug–4 Sep	57	516	12	449	0	300
5–11 Sep	34	464	1	381	0	221
12–18 Sep	5	244	6	240	0	221
19–25 Sep	10	387	11	338	0	221
26 Sep–2 Oct	4	336	1	190	0	255
3–9 Oct	2	216	0	145	0	342

^a Total effort estimates were computed by the sampling and projection techniques described by Kutkuhn (1962).

the data into 10-day time intervals. This did not provide satisfactory mortality estimates because a negative value for c , the slope of the regression line, was obtained. Since fishing mortality is related to fishing intensity $F = cf$, F is instantaneous fishing mortality coefficient, a negative c implies that fishing mortality decreased with increased fishing effort. This is impossible and could result from inadequately marked shrimp recovered in a given time period, bias in the effort data, or variation in availability of marked shrimp. In this study, grouping recovery data into 10-day periods did not provide satisfactory mortality estimates because no fishing effort was expended, nor were any marked shrimp recaptured during Hurricane Cindy on 17 and 18 September 1963. Equal time intervals of 9 days yielded a positive c value. Other regrouping of the data into intervals of less than 9 days was unsatisfactory.

The recovery period was also divided into unequal time periods. It was advantageous to select recovery periods so small numbers of recaptures in any period could be avoided. Fishing effort which either steadily increased or decreased provided the most satisfactory conditions for computation of F and X . Hence, recapture periods listed in Table 3 were chosen so that the fishing effort decreased throughout the study and τ the length of the time interval was chosen as 10 days.

Mortality coefficients were first calculated with recovery data from time intervals 1 through 6 and then a second calculation was made with the data from the intervals 1 through 5 (Table 3). Solutions for the parameter X and c were estimated as 0.121 and 0.000134, and 0.095 and 0.000154 for time

intervals 1 and 2 respectively, and 0.052 and 0.00016 for 9-day time intervals.

The results were remarkably different for the time grouping for which it was possible to estimate F , X , and c (Tables 3 and 6). A close examination of all the variables associated with this investigation was warranted. For example, the value of X provided an estimate of natural mortality when other losses were negligible. If the following assumptions can be satisfied the value of X can be assumed to be a reasonable approximation of the natural mortality.

1. *Mortality due to marking and the loss of marks was negligible or remained constant throughout the study period.* Stains used for marking shrimp do not effect long-term survival and are not shed from the shrimp's body (Costello 1964; Klima 1965). Care was exercised to minimize marking mortality.

2. *No emigration of the marked group out of Galveston Bay.* The degree to which the assumption can be accepted is indicated by the distribution of the recoveries of the marked population. For our purpose the study area was considered to be Galveston Bay. Since the marked group was released in upper Galveston Bay (Fig. 1), all stained shrimp recovered offshore would be considered to have emigrated out of the study area.

Stained shrimp distributed themselves throughout the estuary with slightly more than 85% of them recaptured in the upper portion and 15% in the lower section of the bay (Table 4). No marked shrimp were recaptured outside of Galveston Bay, although more than 2,300 boat days of commercial fishing effort were expended in offshore waters out to a depth of 30 m.

TABLE 5.—*Results of efficiency tests conducted at shrimp plants in Seabrook and Galveston, Texas*

Time period	Number of tests	Number of marked shrimp released	Number recovered	Percent not recovered
August	20	38	32	16.0
September	13	33	26	21.0
	33	71	58	18.0

No significant change in the location of the stained population from one time period to the next is seen. It can then be concluded that emigration from the study area was negligible during this investigation.

3. *Rate of detection and reporting of marked specimens remained constant throughout the study period.* Recoveries were made when the marked shrimp were seen at the time of capture on the vessel, during the unloading at shrimp plants, or when the shrimp were decapitated in the shrimp plants. Texas law states that shrimp caught in Texas bays must be decapitated in the shrimp plants. Thus, marked shrimp not detected at the time of capture could be detected during processing in the shrimp plants. Detection rate and reporting marked recoveries were investigated by tests in various shrimp plants in Seabrook and Galveston, Texas. In the investigations one to four marked shrimp were placed in the hold as the catch was being unloaded. Results showed the loss rate remained approximately constant as about 16 and 21% were lost (Table 5).

After looking at the basic assumptions associated with estimates of mortality, I believe that all these assumptions are fairly well satisfied for this study; however, the estimates of mortality most certainly are in question. It is extremely odd that I was not able to obtain positive c values for 10-day time intervals, whereas for 9-day and unequal time periods I was able to achieve these estimates. Therefore, it appears to me there are other inherent differences which have caused discrepancies in these estimates. One factor may have been a shift in the marked population from the upper to the lower bay. When the first four time periods in Table 4 are compared with the second four time periods it

TABLE 6.—*Comparison of F, X, and Z calculated from different time interval groupings*

Time periods	Calculated average weekly instantaneous mortality rates		
	F	X	Z
1	0.104	0.121	0.225
2	0.131	0.095	0.226
3	0.123	0.041	0.164

it noted that 89% of the recaptures during the first period (15 August–11 September) were from the upper bay in which only about 58% of the fishing effort was expended. In the second period (12 September–9 October) about 56% of the effort was expended in the upper bay, resulting in about 54% of the recaptures. Obviously, during at least the first half of the experimental period the marked shrimp were not uniformly distributed throughout the entire bay. These data also indicate disproportionate emigration between the two time periods of the *marked* population. Consequently, when total effort for the entire bay is used there undoubtedly is a bias in the equation $F = cf$. Another fault probably is that of unequal fishing pressure applied to various segments of the marked and unmarked population. Although the shrimp were distributed randomly throughout the upper bay at the time of release, either one of two things could have happened. The marked shrimp did not remain randomly distributed throughout the bay in relationship to the unmarked shrimp and, consequently, the distribution of fishing effort exerted on the two populations was unequal, resulting in inaccurate estimates of mortality. Another alternative could be that the fishing pressure exerted on both populations was such that it selected, during different time intervals, one portion of the population over the other. An interaction of these two causes could also create the same results. A further factor which could have caused this bias is that the accuracy of the fishing effort was not sufficient for the technique involved.

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